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LIFE CYCLE ENVIRONMENTAL IMPACTS FROM REFURBISHMENT PROJECTS – A CASE STUDY

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Abstract

Environmental life cycle assessments are becoming more commonly applied in the building sector, although the methodological framework for LCA on existing buildings is not as clear as for new constructions. This paper discusses some of the temporal and allocation perspectives of refurbishment LCA studies in the context of the EN 15978 standard. By use of a refurbishment case study, the paper shows an example of the impacts associated with a larger refurbishment, a comparison with reference values for a new construction and the environmental pay-back time of the refurbishment measures implemented.

Keywords: *refurbishment, life cycle assessment, allocation principles, EN15978 standard*

1 Introduction

The environmental sustainability aspect of construction has over the past decade received increased interest from stakeholders in the building sector. However, it is mainly within the area of new buildings that the interest is fuelled, whereas quantifying the environmental impacts from refurbishment activities are less prominent in terms of research.

In the building sector, refurbishment is a broadly used term to describe construction activities that aim to raise the standard of a building, be it standards of comfort or operating costs. The scale of refurbishment intervention varies a lot but is seen to span minor refurbishments of e.g. the interior kitchen up to total transformations of the building lay-out and function, e.g. from industrial purpose to office use. Naturally, the environmental impacts connected with the different scale of these interventions will be of different magnitudes due to the involved amounts of materials and processes. Furthermore, some refurbishments may entail a change in the use stage of the building in question, the most obvious change being the amount of electricity and heating or cooling needed in order to operate the building.

The aim of this paper is, based on a case study, to illustrate the life cycle environmental impacts of a large refurbishment, to evaluate the environmental pay-pack time of the energy efficiency measures installed and to compare the refurbishment impacts with the life cycle impacts of a new construction. Furthermore, some key methodological issues regarding LCA on refurbishments are discussed.

1.1 Refurbishment LCA – in the framework of the EN 15978 standards

The European EN 15978 standard on calculation method for sustainability assessment of buildings does entail an aspect of refurbishment by including refurbishment as a process module in the use stage of the building [1]. This process module, B5, is primarily defined in relation to the construction of a new building, in which scenarios for future refurbishments are defined and included as part of the total life cycle impacts. The refurbishment module B5 is thus, for new buildings, juxtaposed by the other scenario-based and restorative process modules in the use stage: maintenance (B2), repair (B3) and replacements (B4), as illustrated in figure 1.

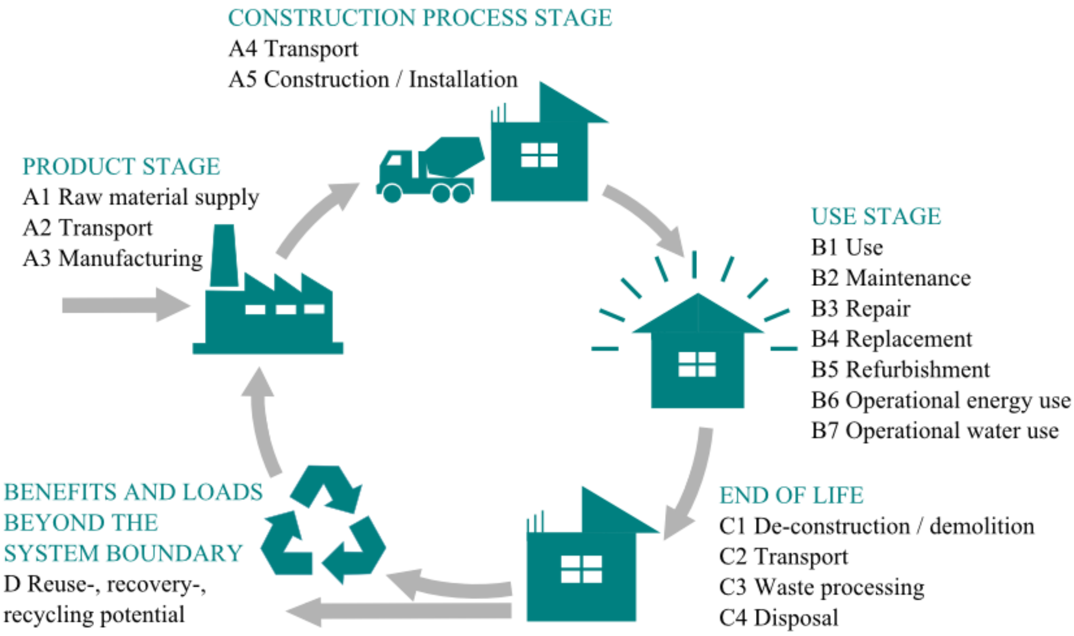

Fig. 1 *Life cycle stages and process modules in the EN 15978 standard*

However, when calculating the environmental impacts of a refurbishment project on an existing building, the starting point of the life cycle under scope changes. Thus, B5 is no longer scenario based, but based on contemporary inventory data at hand, describing the refurbishment measures and marking the starting point of the building's second life. In the cases of existing buildings for which no previous LCA has been made, the refurbishment impacts are then, according to EN 15978, allocated to the A1-A5 modules, as if the refurbishment measures entail the construction of a new building. Implicitly, this leaves the impacts of the existing building out of scope. An important reasoning for leaving out these impacts lies in the viewpoint that the impacts have already taken place and thus cannot become physically undone regardless of the decisions that may be taken on the basis of a refurbishment LCA. From a single-project focus on LCA for decision support this holds true due to the sheer physical realities of the impacts happening. However, the decision about refurbishing the building was already in place at the time of the assessment. The allocation approach considering the existing structure is thus mainly investigated to illustrate a cross-temporal perspective on environmental sustainability where the inherent environmental value, i.e. the resource use and impacts already "invested" but not fully utilized in terms of service life, is accounted for.

Different viewpoints and practices exist regarding the calculation of impacts from the existing building. Itard and Klunder (2007) avoid the allocation issue by calculating the total cumulative environmental impacts over the renovated building's entire service life – back in time [2]. Other studies disregard the potentially allocated impacts from the existing building, for instance by argument of encouraging reuse [3], or by simply using a different approach within the many existing reuse/recycling allocation approaches [4][5].

Naturally, the purpose of the individual refurbishment LCA study influences the exact method used and the perspectives put on the existing building. However, in order to evaluate the sensitivity of the conclusion in a comparison between new and refurbished buildings, there may be reason in applying different allocation keys regarding the impacts from the existing building.

2 Refurbishment case study - method

The environmental impacts of the chosen case study are calculated in a simplified life cycle assessment based on the EN 15978 standard. For this study, accumulated impacts from the following life cycle stages are included: Extraction of raw materials, transport to manufacturing, manufacturing process, use stage replacements, waste handling and disposal. The life cycle stages accounted for in the case study is but a selection of the proposed building life cycle stages from the EN 15978.

Results of the refurbishment case study are compared with the reference values for new buildings incorporated in the Danish DGNB system for sustainable buildings. The reference values of the varying environmental impacts reflect the average LCA score obtained within the buildings certified and within the framework of the DGNB methodology, corresponding to the simplified approach applied for the case study of this paper.

The results of the refurbishment case study are evaluated at two approaches for allocating the impacts from the existing building. Furthermore, the embodied impacts of the refurbishment measures are evaluated in terms of environmental pay-back time from the resulting savings in operational energy use.

2.1 The case study

The functional equivalent of the case study is a refurbished residential complex with a 50-year assumed service life after refurbishment and with the following specifications:

The case study, is a complex of three residential 14-storey buildings erected in 1960 and known be the name Sorgenfrivang. The blocks contain a total of 428 flats varying in size from 26 m^2 to 130 m2 gross floor area. The total gross floor area of the three buildings is 41,991 m^2. The buildings are located in Virum, Denmark. The annual energy consumption before refurbishment was measured at 112 kWh/m^2 district heating and 5.7 kWh/m^2 electricity.

Refurbishment measures include:

- Building shell: insulation of roof and new roof covering, gable and socket insulation, façade element replacements, low energy windows, new balconies
- Interior: new stairwells, elevators, new kitchen and bathroom units
- Technical: new heating distribution system, new ventilation system, new electrical installations, photovoltaics

Fig. 2 *One of the three Sorgenfrivang blocks prior to refurbishment. Illustration by DOMINIA Consulting Engineers.*

Annual energy consumption after refurbishment is calculated at 52 kWh/m^2 district heating and 6 kWh/m^2 electricity. Standard number of heating degree days in Denmark is 2,906 [6].

2.2 Modeling of case study

For the case study LCA modelling, a simplified approach was taken in which only the elements accounted for in the Danish DGNB certification system were modelled. Thus, only central technical components were included in the inventory (e.g. ventilation aggregates included but not ventilation ducts). Furthermore, kitchen and bathroom units are not included and neither are surface coatings nor fittings and fixtures for the constructions.

LCIA data used for the modelling is from the Ökobau 2013 database [7] (photovoltaic dataset from Ökobau 2015 [8]) when it comes to materials, and from the Danish DGNB certification system when it comes to data on national district heating and electricity for energy consumption in the use stage [9].

The reported impact categories are global warming potential (GWP) ozone depletion potential (ODP), acidification potential (AP), eutrophication potential (EP), photochemical oxidant formation potential (POCP) in accordance with the CML methodology (ref). An additional resource use category, the total primary energy use (PEtot) is included, covering the use of renewable and non-renewable sources.

Scenarios for replacement of materials are set based on values from a Danish research project on durability of building materials in sustainability assessments [10]. Scenarios for end-of-life treatment of building materials follow the general predefined flows for material groups defined in the Danish DGNB system [9].

2.3 The existing structure - allocation approach

The comparison of the refurbishment with a new building is carried out at two distinct viewpoints of allocating the environmental impacts of the existing building structure;

- Allocation I: where the impacts are regarded as offset (hence “burden free”) at the time of the refurbishment, i.e. the existing structure comes for free in the refurbishment project
- Allocation II: where the impacts from the existing building structure is temporarily allocated in accordance with the expected service life of the existing components. E.g. when slabs have expected service lives of 100 years in total and the refurbishment takes

place after 56 years, 100-56 % = 44 % of the embodied impacts from the slabs are allocated to the refurbishment project

Inventory of the building elements in the existing structure cover the following: concrete foundations, slabs and walls, gypsum ceiling, wooden/tile flooring as well as internal gypsum walls within the apartments.

3 Refurbishment case study – results

Potential impacts from the life cycle stages forming part of the refurbishment intervention are reported in table 1, distributed on the GFA of 41,991 m^2 and the reference study period of 50 years. For all impact categories, the production stage of the materials used for the refurbishment is the dominating life cycle stage, accounting for 57-68 % of the total calculated impacts depending on the category. Scenario based replacements account for 32-36 % of the calculated impacts and the scenario based end-of-life impacts for materials installed in the refurbishment account for up to 9 % of the GWP category, although the corresponding numbers from the other categories are somewhat lower, between 0.1-2% of the calculated life cycle impacts. The end-of-life processes of the demolished materials from the refurbishment process account for up to 2 % of the life cycle impacts from the refurbishment.

Tab. 1 *Impacts from life cycle stages of the refurbishment measures*

Life cycle stage (process module, according to EN 15978)	GWP [kg CO_2-eq/m^2/y]	ODP [kg R11-eq/m^2/y]	AP [kg SO_2-eq/m^2/y]	EP [kg PO_4-eq/m^2/y]	POCP [kg C_2H_4-eq/m^2/y]	PEtot [MJ/m^2/y]
Production, refurb. material (A1-A3)	1.75	1.6E-08	8.7E-03	8.0E-04	8.1E-04	34.7
Replacements, refurb. materials (B4)	0.96	7.4E-09	4.9E-03	4.3E-04	4.8E-04	19.3
EoL, refurb. materials (C3-C4)	0.29	1.9E-11	1.3E-04	2.5E-05	1.8E-05	0.31
EoL, demolished materials (C3-C4)	0.07	5.7E-12	4.3E-05	9.4E-06	5.0E-06	0.09
Total from the refurbishment	**3.07**	**2.3E-08**	**1.4E-02**	**1.3E-03**	**1.3E-03**	**54.4**

Figure 3a illustrates the impacts from the operational performance of the Sorgenfrivang building before refurbishment and after refurbishment, both in relation to a reference building, as defined in the Danish DGNB certification system, reflecting the minimum requirements of the national building regulations in force at the time of the project approval. The impacts from Sorgenfrivang before refurbishment are 150-200% of the corresponding impacts of the reference building. For the refurbished Sorgenfrivang on the other hand, impacts related to the operational energy use come close to, although a bit better than, the impacts associated with the reference building, reflecting the minimum requirements of the national building regulations in force at the time of the project approval.

Figure 3b illustrates the embodied impacts of the refurbishment project at two levels of allocation and in relation to the embodied impacts of a reference building. By the allocation I procedure, embodied impacts correspond to 20-30 % of reference building’s embodied impacts in all categories but ODP. By the allocation II procedure, embodied impacts correspond to 40-50 % of embodied impacts in all categories but ODP.

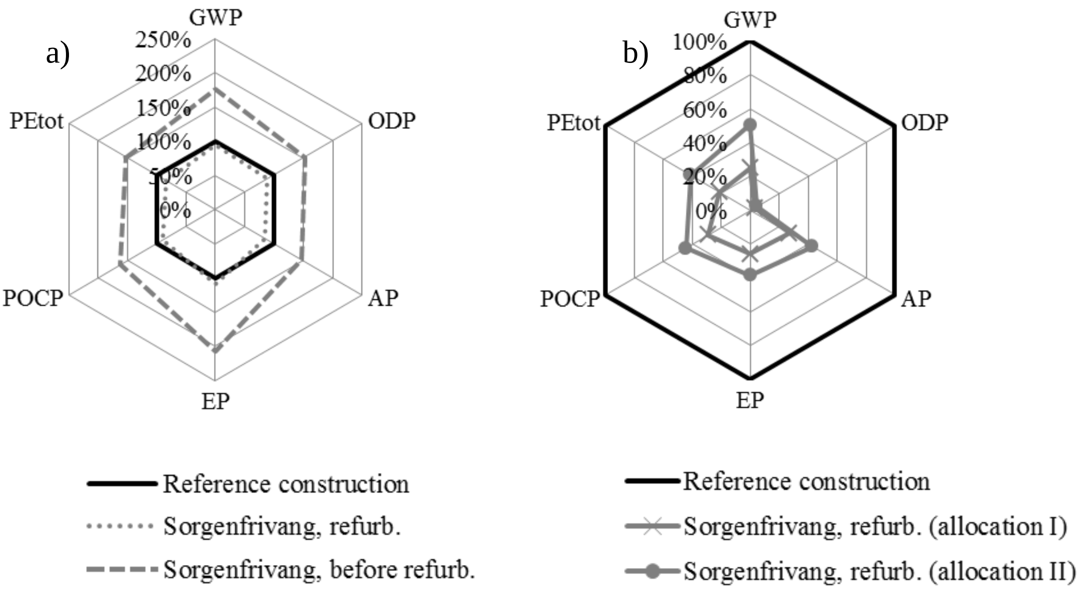

Fig. 3 *a) Impacts from the operational energy use (module B6) of Sorgenfrivang compared with a reference building. b) Embodied impacts from the material use (modules A1-A3,B4,C3-C4) of the Sorgenfrivang refurbishment. Allocation I: the existing structure is accounted for as "free". Allocation II: existing structure is accounted for by remaining service life of building elements.*

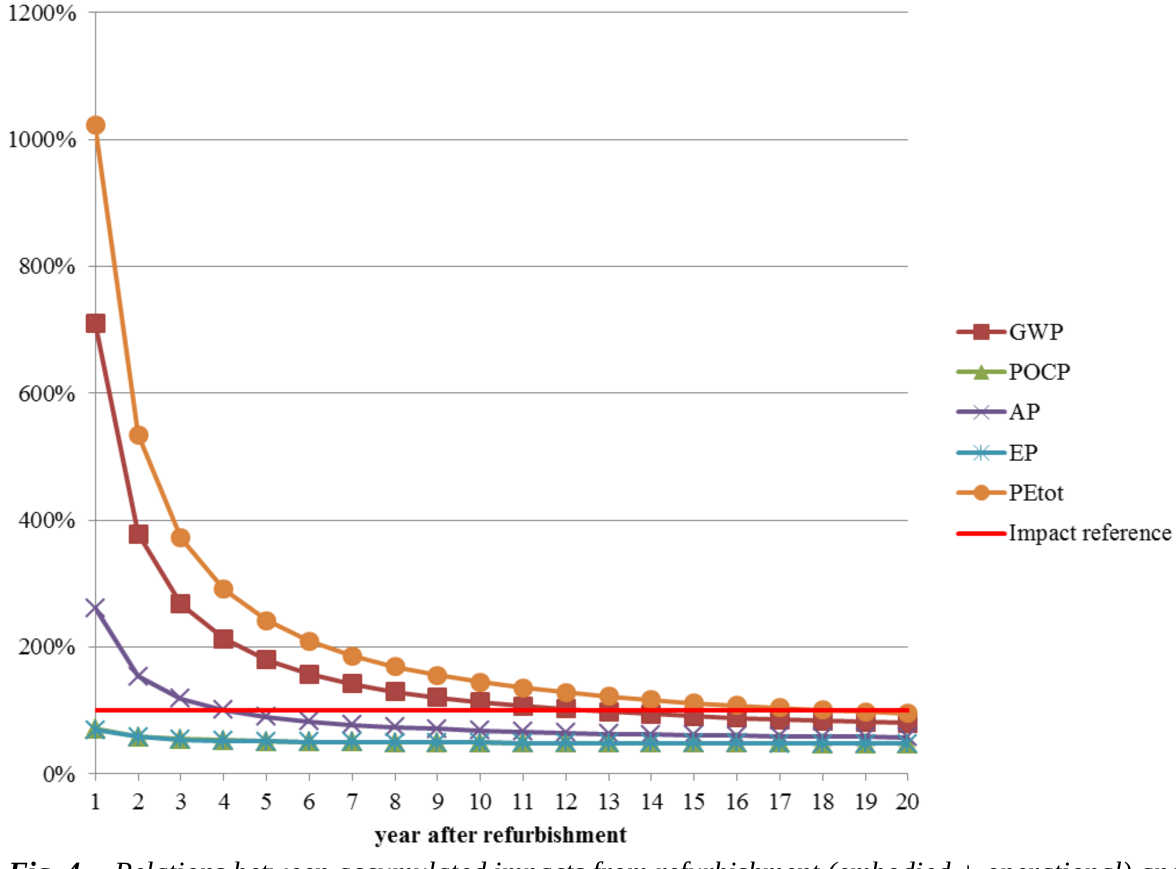

Fig. 4 *Relations between accumulated impacts from refurbishment (embodied + operational) and from a BAU scenario without refurbishment and thus correspondingly larger annual impacts from operation. Intersections at 100 % impact reference, denotes payback time of the different categories.*

Figure 4 illustrates the environmental pay-back times of the refurbishment measures in relation to impact savings from the reduced operational energy use. The impact reference denotes the accumulated impacts from the building's operation in the event that the building was not refurbished - a business-as-usual (BAU) scenario. For all impact categories this is for all years set as the relation mark at 100 %. Each impact category is then marked in the relation between the impacts from refurbishment (embodied + accumulated operational) and the corresponding impact reference at a given year. The point in time where an impact category graph intersects the impact reference denotes the environmental pay-back time of the refurbishment "investment" compared with a BAU scenario. For categories POCP and EP, the impact from the refurbishment is already offset at the first year of operation due. For AP the impact from refurbishment is offset at 4 years, for GWP at 13 years and for PEtot at 18 years. Note that ODP is omitted from the visualization due to the fact that the environmental pay-back time fell within a theoretical time frame of several thousands of years.

4 Discussion

Time perspectives of a building's second life span, after larger refurbishments, have shown to influence the results obtained from comparisons of refurbishment versus new construction [11]. Essentially, this aspect concerns the distribution of embodied impacts from the refurbishment measures on the predicted service life. This evaluation is not performed in the current project although it is possible to say that the environmental pay-back times presented naturally would be longer if the second lifespan of the refurbished building is shorter than the 50 years assumed.

An additional aspect of time is the estimation of the existing structure's inventory. Estimations on material use are done from present-day building techniques although material efficiency in production and use has improved significantly during the past 50 years. Correspondingly, the background LCIA data for the production processes for the existing building are contemporary and thus do not reflect the actual emissions nor the receiving environment that was actually affected at the time of the production of the existing building.

Operational impacts from energy consumption are often, for existing buildings, seen to influence life cycle impacts significantly. Thus the scenarios chosen for the energy production potentially influences the results of the environmental pay-back times in the sense that future energy production with probable lesser impacts per kWh will postpone the offset of embodied impacts from the refurbishment measures.

The ODP results of the refurbishment LCA diverges from the pattern set by the other categories due to several factors, one being the very low ozone depleting emissions connected with the energy production technologies, thus resulting in a practically infinite pay-back time for the refurbishment measures. Furthermore, the reference ODP values for new constructions seem too high to compare evenly with this type of building project, underlining the importance of critically evaluating generic references for specific building projects.

5 Conclusion

This paper provides a case study based example of the environmental life cycle impacts of a larger refurbishment. The refurbishment has some obvious material based impacts from the life cycles of installed materials. However, these embodied impacts are, except from ODP, offset within a time frame of less than 20 years by the expected impact savings from reduced operational energy.

A comparison of the refurbishment project with generic reference values for a new construction shows that the refurbishment measures are expected to bring the impacts from operational energy use down to a level corresponding with the minimum requirements from the building regulations for new buildings. Furthermore, the life cycle embodied impacts from the refurbishment measures are only around 45 % or 25 % of the embodied impacts from a new construction, depending on allocation procedure for impacts from the existing structure.

Environmental sustainability in refurbishment projects can be discussed from quite different viewpoints because the temporal aspects of potential burden sharing between first and second life spans are in contrast to the single-project perspective applied in most building and refurbishment LCAs. A future development of guidelines for refurbishment LCAs could help clarifying the different issues in this regard and is thus recommended as an area of research in the pursuit of a more sustainable building sector.

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